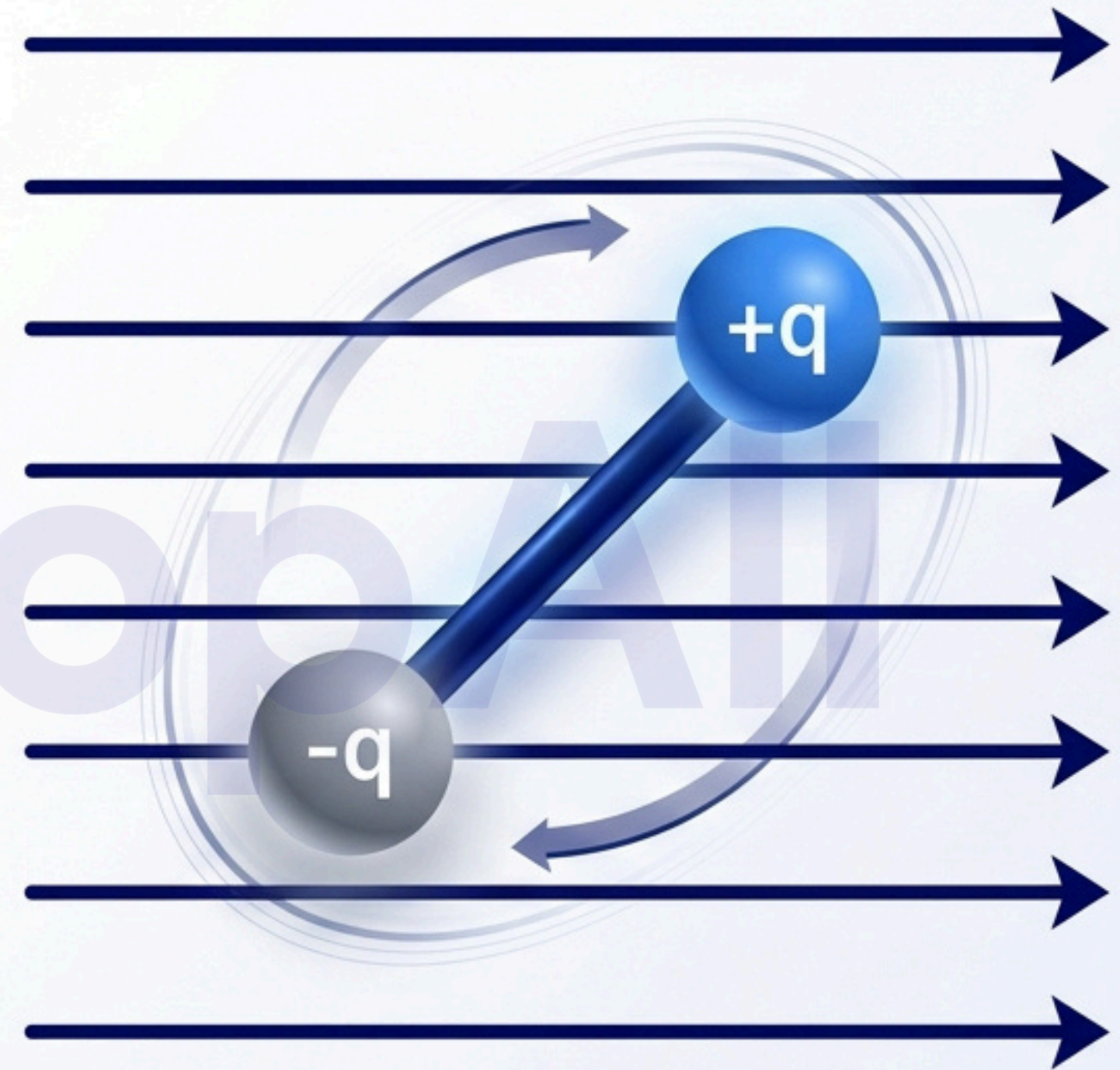


Dipole in a Uniform External Field

Zero net force, but not zero rotation.

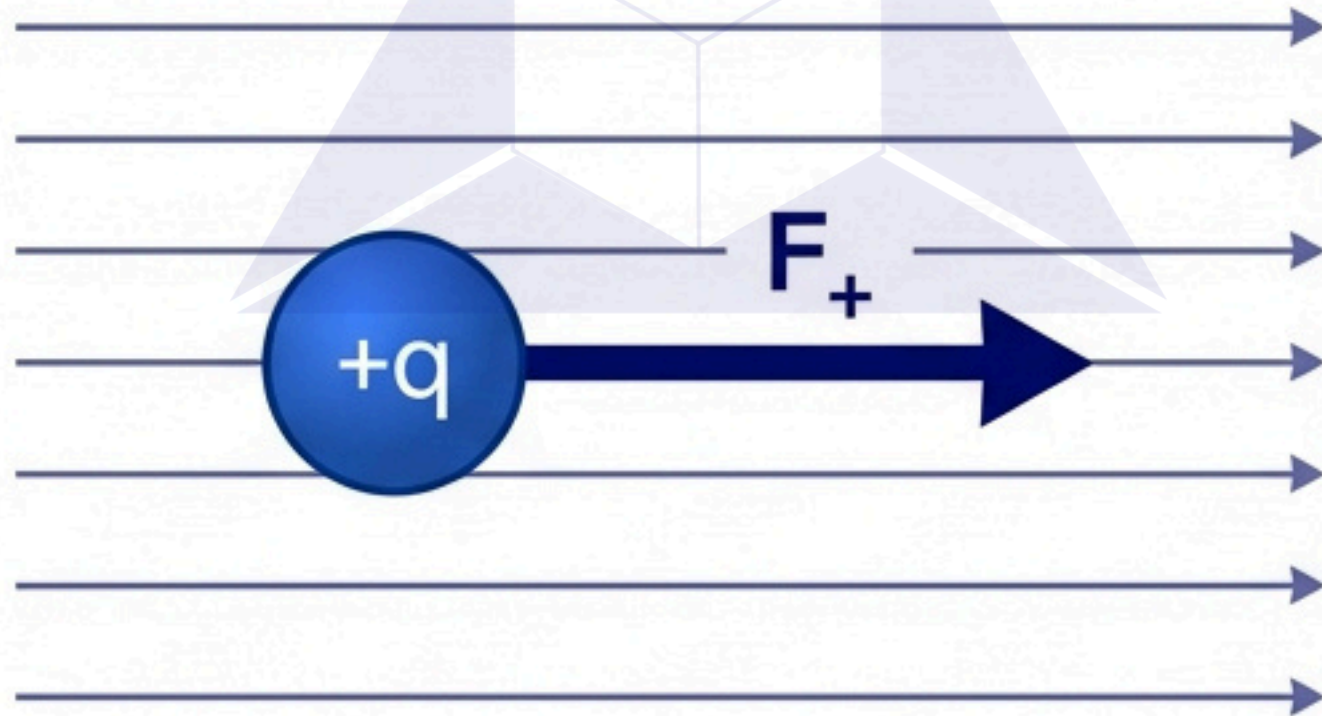


The Actors: Forces on $+q$ and $-q$

$+q$ moves with the field

$$F_+ = +qE$$

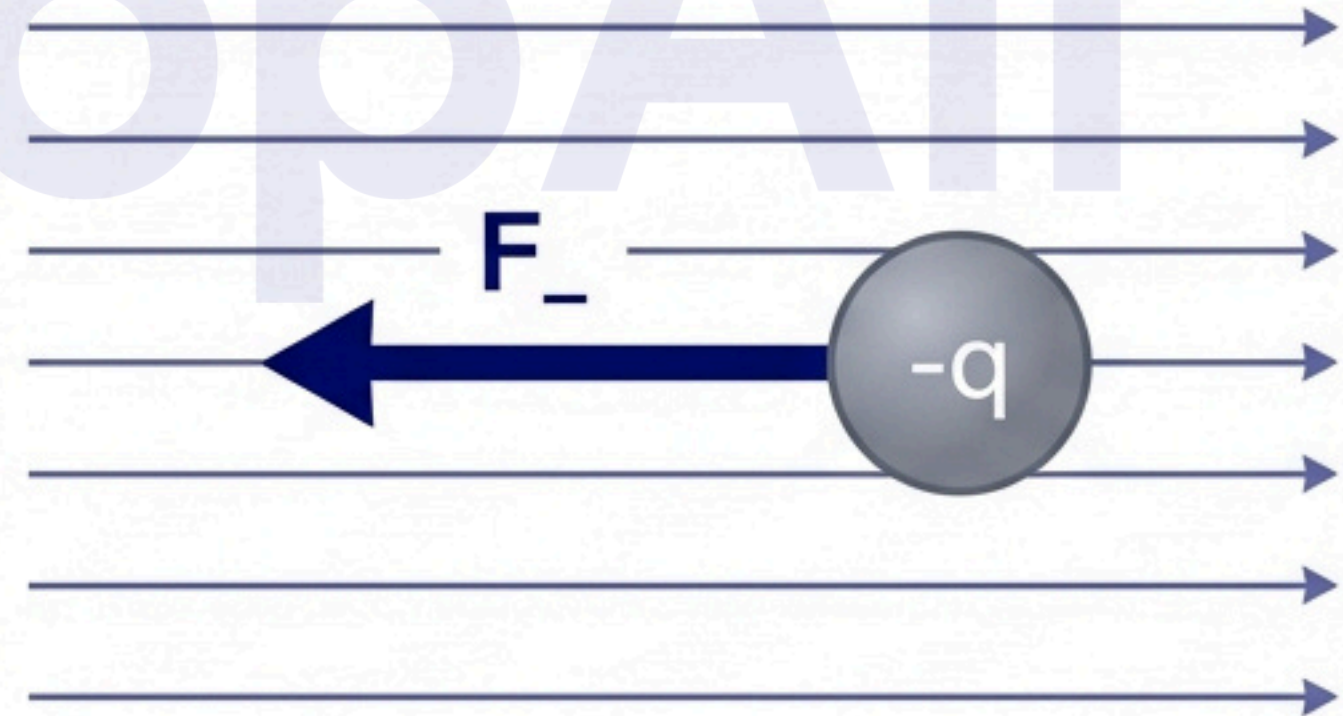
The force vector acts strictly along the direction of the uniform field.



$-q$ moves against the field

$$F_- = -qE$$

The force vector acts strictly opposite to the direction of the uniform field.



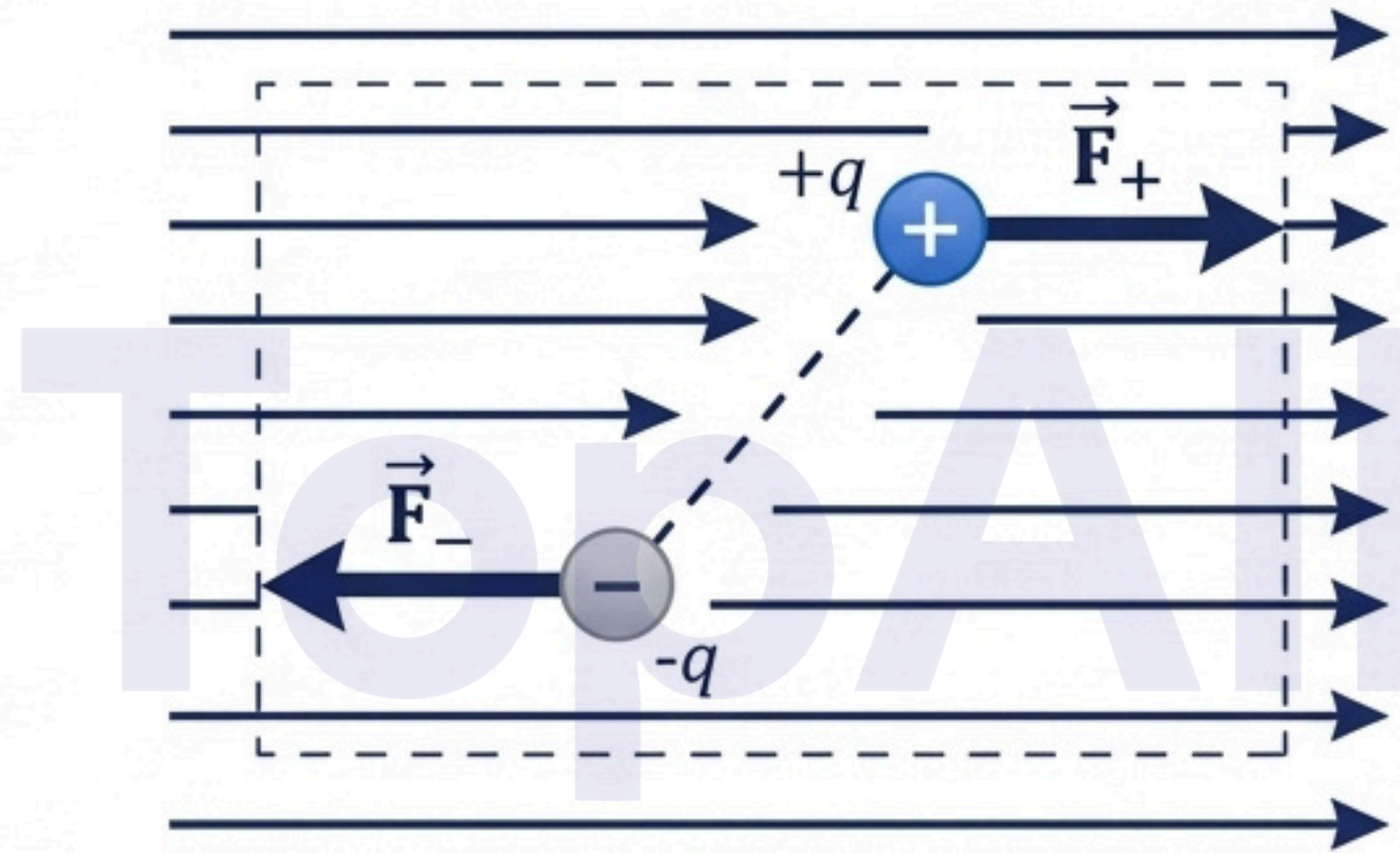
Why the Net Force is Exactly Zero

$$F_{\text{net}} = F_+ + F_-$$

$$F_{\text{net}} = qE + (-qE)$$

$$F_{\text{net}} = 0$$

Translational Equilibrium
(No linear motion)



Exam Trap

Caution: Non-Uniform Fields

If the field is **NOT** uniform ($\mathbf{E}_1 \neq \mathbf{E}_2$), then qE_1 does not perfectly cancel $-qE_2$. A **net force WILL** exist! Never assume $F_{\text{net}} = 0$ unless the word “uniform” is present.



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$$E=mc^2$$



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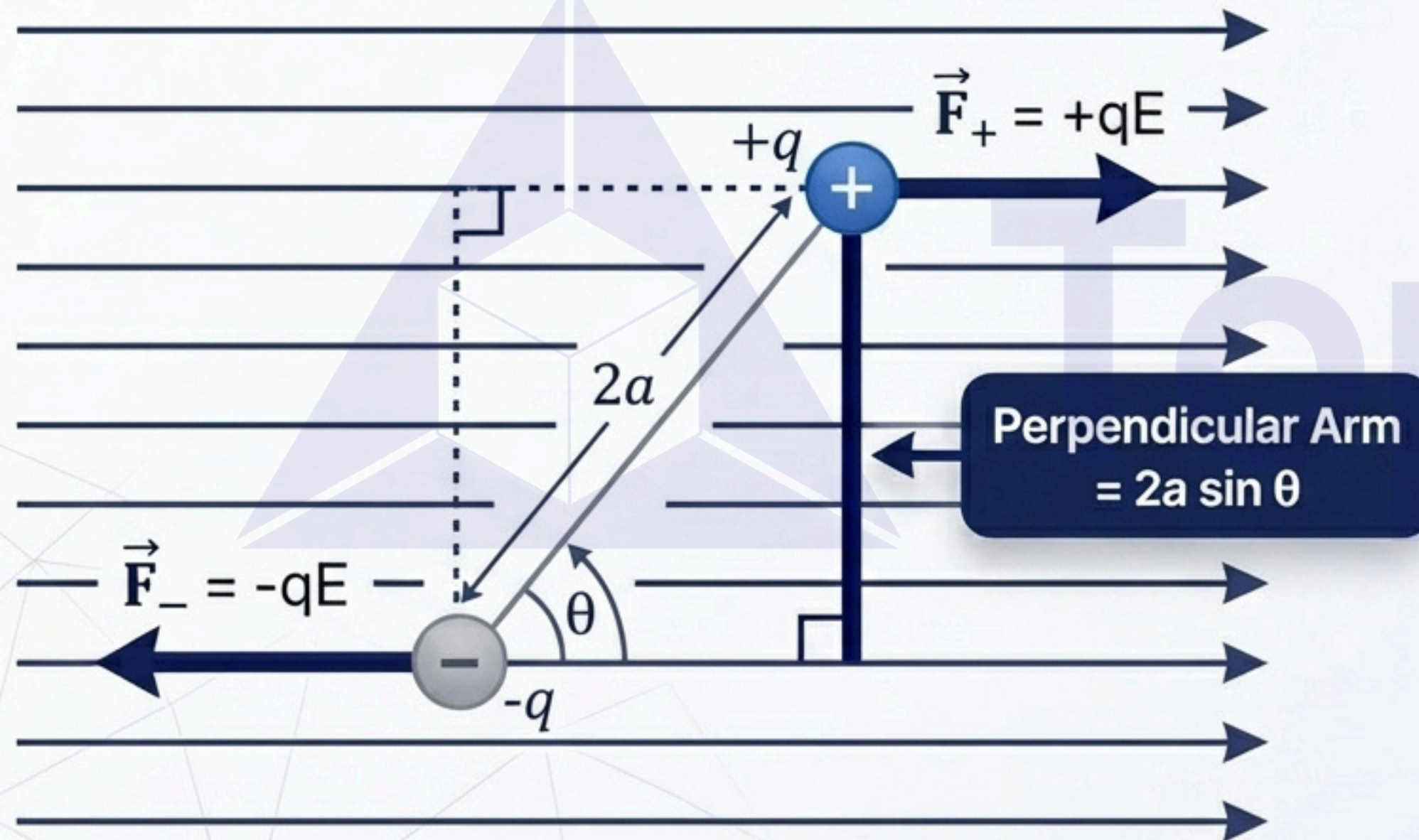
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Why Torque Exists: The Couple

Couple-Arm Exploder



- Although the forces are equal and opposite, they act at **different points**.

- They do not share the same **line of action**.

- This offset creates a “**couple**” — a turning effect that forces the dipole to rotate.

Deriving the Torque Formula

Step 1: Torque (τ) = Force $\times$ perpendicular distance

Step 2: $\tau = (qE) \times (2a \sin \theta)$

Step 3: Rearrange using Dipole Moment ($\mathbf{p} = 2aq$):

Step 4: $\tau = (q \times 2a)E \sin \theta$

Scalar Form: $\tau = pE \sin \theta$

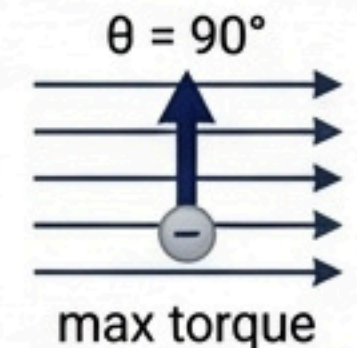
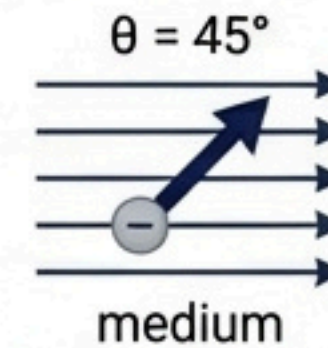
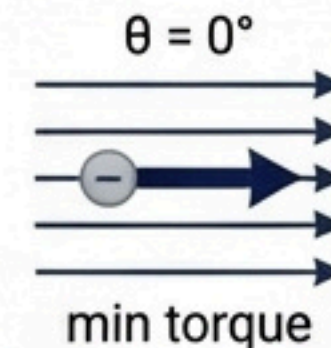
Vector Form: $\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$

Variable Breakdown

$\mathbf{p}$ = dipole moment

$\mathbf{E}$ = electric field

θ = angle between $\mathbf{p}$ and $\mathbf{E}$

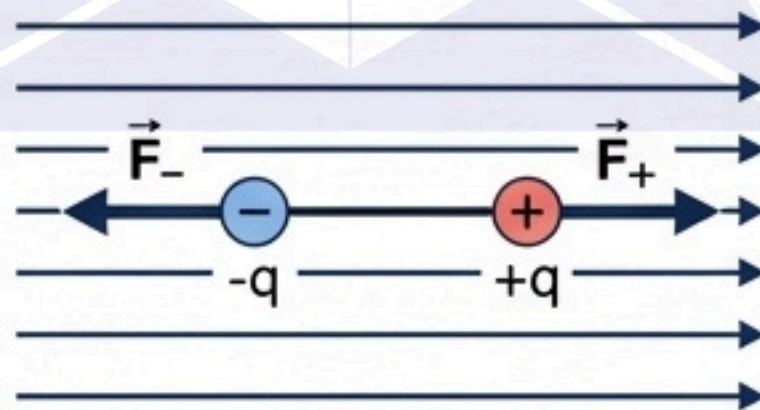


The End State: Stable Alignment vs. Net Attraction

Uniform Field

The torque forces the dipole to rotate until it aligns parallel with the field ($\theta = 0^\circ$).

$$\tau = \mathbf{pE} \sin(0^\circ) = 0$$

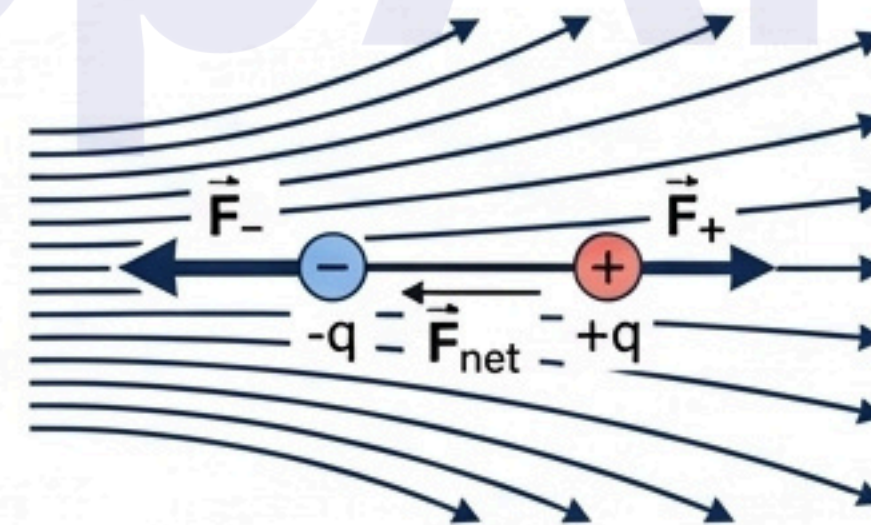


✓ Stable Equilibrium

Non-Uniform Field

If $\mathbf{E}$ isn't uniform, the dipole aligns AND experiences a net pull toward the stronger field region.

Example: A charged comb attracts neutral paper.



Key Takeaways

1. **Uniform Field = 0 Net Force** (Translational Equilibrium).
2. **Offset lines of action create a Couple** (Torque).
3. **Vector Formula:** $\tau = \mathbf{p} \times \mathbf{E}$ (Aligns dipole to the field).

Check Your Understanding

Q: If a dipole is placed perpendicular (90°) to a uniform E-field, is the torque maximum or minimum?

Answer: Maximum. ($\sin 90^\circ = 1$)

Q: What is the direction of torque if $\mathbf{p}$ is pointing along the $+x$ axis and $\mathbf{E}$ is pointing along the $+y$ axis?

Answer: $+z$ direction (Out of the page, via right-hand rule)

Next Module: Continuous Charge Distribution →



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